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# Random Foams: Instabilities, Fracture and Shocks

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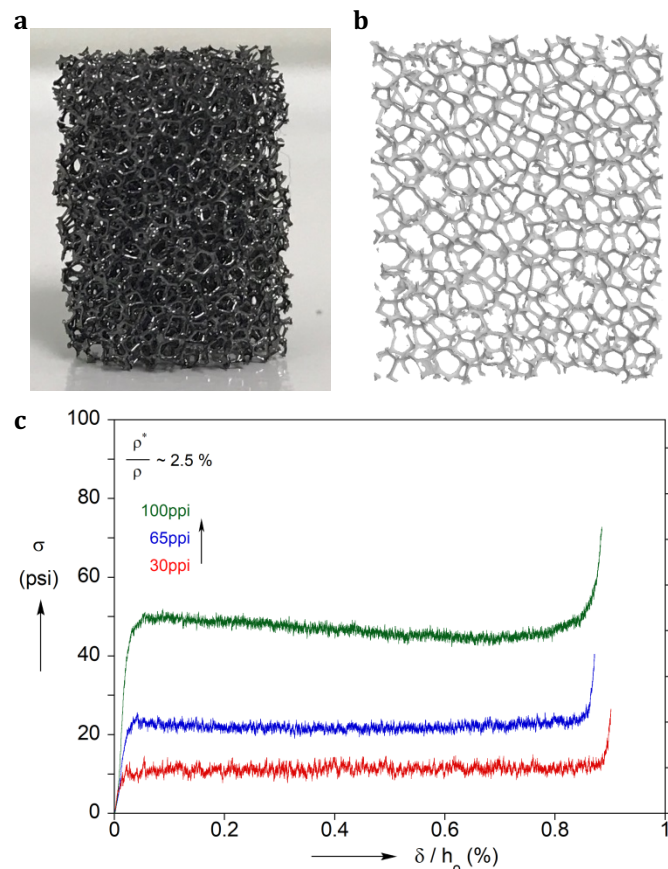
## KEYWORDS:

Foam Crushing, Brittle Fracture, Instabilities

Cellular solids are Nature's solution to the need for efficient, lightweight but strong materials. Inspired by these naturally evolved cellular structures, foams fabricated from a wide array of solid constituents are desirable for a broad range of applications including shock absorption, thermal and acoustic insulation among others. Understanding the connection between their microstructure and these attractive material properties is essential in the adoption and optimal use of cellular materials in engineering design. This talk will focus on the mechanical behavior of open-cell foams, which is governed by the intricate connection of topology and constituent material behavior, and the different deformation mechanisms that they exhibit. These include failure of the base material due to yielding or brittle fracture as well as elastic instabilities [1]. Here we will present combined experimental and numerical efforts to study the crushing response of elastic, brittle and ductile foams under compressive loads and discuss their similarities and differences.

In the case of polymeric foams it has been shown that their compressive response is governed by elastic buckling. However, depending on geometric and loading conditions different type of instabilities might occur, ranging from microscopic instabilities at the cell level to global (long wavelength) buckling. In this work, we use the Bloch wave theory to examine the critical bifurcation mode under different loading conditions and derive micromechanical models that capture the post-buckling response, from localization to densification.

On the contrary, when the base material is brittle (usually in the case of rigid polymeric or ceramic foams) then fracture governs the material response. We will present results (Figure 1) from experiments on both Reticulate Vitreous Carbon (RVC) foams as well as carefully designed brittle polymeric foams synthesized by Additive Manufacturing (AM). Specimens of different geometries and dimensions are crushed between rigid surfaces in order to examine the effect of boundary conditions, specimen size,

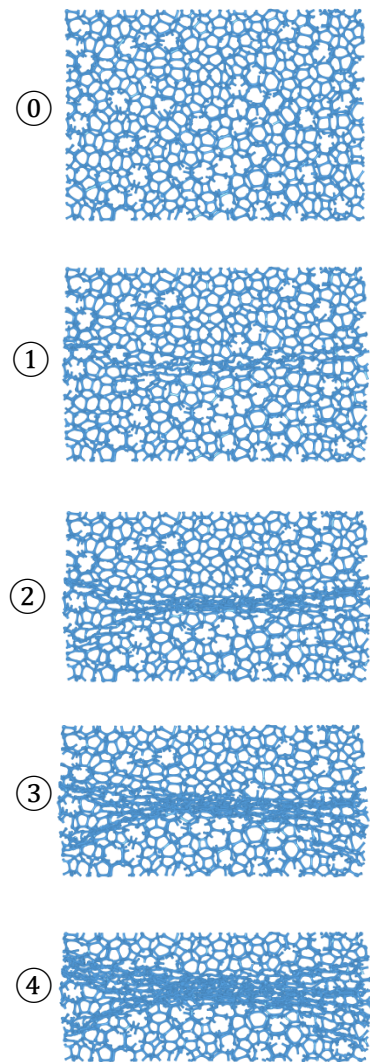


**Figure 1** a. Open-cell carbon foam with 30ppi b. X-ray tomography image of a cross-section. c. Crushing response of brittle foams with different cell-size.

relative density and cell size on the resulting response and the associated fracture strength of the foam. Foam specimens of 30, 65 and 100 pores per inch (ppi) are crushed using both a classical MTS Testing Machine as well by combining X-Ray tomography (SkyScan 1172) with in-situ mechanical testing. Image analysis based on scan data can be utilized to observe the failure mechanism and associate it with the recorded force-displacement response.

Finally, we will discuss how the quasi-static response of foams leads to shock-type crushing phenomena in super-critical impact velocities. In contrast to quasi-static type localization, a front of collapsed cells forms at the impact plane and propagates to the distal end. This mechanism is accompanied by a discontinuity in the stresses, the strains, and the energy across the shock front. The material behavior in this regime is completely defined by the foam Hugoniot. Results from the dynamic crushing of open-cell aluminum foams will be presented [1].

In all three cases examined here micromechanically accurate numerical models (Figure 2) are first developed and then validated against experiments. In summary, Laguerre tessellations originating from dense packings of polydisperse spheres are used as initial conditions in *Surface Evolver* to generate soap froth that satisfies Plateau's laws [2]. The resulting structures are further relaxed through additional topological transitions produced by large deformation tension-compression cycles. These geometries are subsequently dressed with shear deformable beam elements, with a non-uniform material distribution that mimics measured values derived from tomography images. These predictive models have been shown, in the case of metallic foams, to accurately reproduce all aspects of the foam crushing behavior, from the onset of localization and propagation of collapsed cells to densification, and furthermore the dynamic enhancement and shock-type crushing under impact loads [3-4]. This modeling framework, once validated, can be used to further explore the connection between key morphological characteristics of the underlying microstructure, such as the relative density [5] and statistical cell-size variations [6], and the resulting mechanical properties.



**Figure 2** Numerical modeling of the quasi-static crushing of open-cell metal foam.

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